*Journal of Social Issues, Vol. 63, No. 1, 2007, pp. 155–174*

# Technology's Four Roles in Understanding Individuals' Conservation of Natural Resources

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*An overview is presented of four ways in which human beings and technology interact with respect to the conservation of natural resources. The four roles technology plays are: (1) as intermediary, (2) as amplifier, (3) as determinant, and (4) as promoter of environmentally significant behavior. A review of pertinent literature supports the conclusion that behavioral scientists can contribute considerably to reducing overall environmental impact by analyzing human behavior and technology in concert. Problems and opportunities for interventions aimed to enhance resource conservation are discussed, such as rebound effects, allocation of control, and communication with users through technological-environmental and sensory inputs. A major conclusion is that well-designed technical environments, systems, and products have a great potential for supporting environmentally sustainable behavior.*

Since man first stood upright and struck a piece of flint to make a spark, the use of natural resources and technological development has marched hand in hand. As civilization emerged from our increasing control over nature that (agricultural) technology gave the world, population increased and so, again, keeping pace, did technology and the use of natural resources. From the industrial revolution onwards the stamp of human activity on our ecosystems could not be ignored. The impact of human behavior on the natural environment has now led to transformations that have the power to amplify ordinary weather phenomena into increasingly more devastating disasters.

The environmental impact of people, whether as individuals, as households, or as societies, can thus be roughly assessed as a function of their numbers, their affluence, and the technology they currently use (cf. Ehrlich & Ehrlich, 1991;

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see also Vlek & Steg, this issue). However, despite the fact that humans have used technology as long as they have consumed natural resources, technology as related to environmental resource use is often set apart from the study of human behavior and resource conservation.

This article is designed to return the focus to the relationship of humans and the roles their technology plays in the individual consumption of natural resources. The reader is given an overview of what the authors believe to be technology's four most critical roles, where it serves as: (1) an *intermediary*, (2) an *amplifier*, (3) a *determinant,* and (4) a *promoter*. Although there are crossovers between some of these divisions, while in others there might be subareas that should perhaps have their own section, we feel that the four divisions chosen provide a pragmatic starting point for future in-depth theoretical and empirical exploration that lies beyond the scope of this article. This introduction orients the reader to these four areas of influence, and it is followed by four sections providing corresponding in-depth discussions. Prior to the conclusion section there is a discussion of conditions underlying the acceptance and use of new technologies for resource conservation.

The first and perhaps the easiest role to understand is technology as an *intermediary*. As an intermediary, technology stands between the behavior an individual carries out to reach a certain goal, and the use of natural resources on the way to that goal. In daily Western life technology is ubiquitous and hardly any move is possible without the use of some sort of technology. If we think in terms of ourselves awaking to the sound of an alarm, taking a shower, and having a cup of coffee with a piece of fruit, simply the choice of whether or not the fruit had to be grown indoors or outdoors makes an impact on our ecological footprint for the day. It can thus be said that in viewing technology as an intermediary, the behavior pattern of the entire person is taken into account.

The second role, where technology serves as an *amplifier,* takes a different perspective on the linkage between behavior and the use of natural resources. Here we make the distinction that the consumer has chosen for a technology that clearly enhances, extends, or amplifies his or her goal attainment. As a side effect, behavior becomes progressively more resource-consumptive as well. Thus, the amplifier role creates the basis for rebound effects, where efficiency gains are getting dissolved due to amplified consumption. Using again our morning wake-up example, we might talk about the computer as (only) an intermediary, if we program it to make a wake-up call for that morning. However, if we take a larger view of computers in everyday living and discuss how they have provided us with myriad ways to share information with others, not the least of which is handing out our own home-printed photos—which have in turn created a whole industry of cameras, printers, software and photo paper for self-made photographs, then we are talking about amplification of both consumer performance and consumption of natural resources.

Where technology as an intermediary or as an amplifier is easiest viewed as technology that we choose to intercede between our behavior and its consequences, technology as a *determinant* can be viewed as that which directly influences our environmental behavior. It is contextual technology that surrounds us, and can either help or hinder conservation-related actions, but we might not even notice this. Technology in the role of a determinant is about channeling or shaping behavior apart from people's motivation. The availability of a car, for example, makes its use more likely, while the absence of it obstructs use drastically. At the same time, the comfort of modern cars with silent engines and ergonomic seats tempts drivers to go faster or lure them into longer rides. However, fuel consumption feedback by on-board computers might motivate users for controlling their speed, thus fitting better into the role category of technology as a *promoter*, described below.

Technology that is specifically designed to promote behavioral choices leading to the conservation of natural resources, differs from determinant technology in its emphasis on the motivation of the user. Technology that promotes conservation behavior can come in several forms such as norm-activating litter receptacles, electronic appliances that allow the user to set a conservation goal and receive feedback, and computer games by which one learns to save water, to name only a few. Many of the technologies falling into this category boast their own specific collection of studies and literature and the reader will be referred to reviews where appropriate.

## Technology as Intermediary

People employ various, more or less sophisticated, forms of technology for many types of behavior, which makes these behaviors resource-consumptive as they unavoidably utilize the environment in which they take place. Even taking a leisurely walk down the street involves, for instance, rubbing off microscopic pieces of concrete from the pavement, and leather particles from one's shoes. Technical products such as cars, computers, and even shoes can thus be seen as a form of intermediary between a given behavior and its environmental consequences. Along these lines, the overall environmental impact of individuals is recognized as a function of people's affluence and of the technology they employ (cf. Ehrlich & Ehrlich, 1991).

Affluence determines the particular technical appliances people can afford (cf. Scheuthle, Carabias-Hütter, & Kaiser, 2005). This is most evident when people purchase high-end devices, such as solar panels or energy-efficient cars. Naturally, technical systems, such as cars with different levels of horsepower or types of fuel system, differ quite substantively in their environmental consequences. These consequences depend, for example, on the type and amounts of fuel consumed or on the emission of pollutants, even when the cars serve the same purpose, that is, effectively moving between locations (cf. Stern, 2000a). In addition, the environmental impact depends on the specifics of how, when, and where the technology is used. Unsurprisingly, the environmental impact of technical means used for certain actions or a given lifestyle often is neither self-evident nor directly perceptible, which to some extent becomes obvious in the fact that the quantitative relationship between impact estimates and scores for individual behavior patterns, with correlations around .35, is far from strong (e.g., Tanner, Kaiser, & Wölfing Kast, 2004).

The situation is even more difficult as most behaviors concurrently draw multiple and often incompatible consequences in terms of energy expenditure; air, soil, and water pollution; greenhouse gases and toxic waste emissions, which cannot easily be balanced against each other. For example, should one replace one's old car with a more fuel-efficient new model despite the premature waste of production-related energy and natural resources? Or should one buy energy-efficient light bulbs despite the fact that they contain traces of mercury? Inevitably, the choice of the proper technology can be a nightmare especially when even conscientious actors lack the necessary knowledge.

Next to affluence and technology, the fact that people are constantly involved in all sorts of more or less environmentally relevant activities is the third source of a person's overall environmental impact. Selections of technical means for different activities may not be independent. In modern societies, people can normally realize their individual goals and ambitions in various ways, which leaves them with options on the technologies employed. Instead of running energy-efficient washing programs, environment-friendly people can switch to a vegetarian diet, or focus more on environmentally benign means of transportation. Because people can choose between various conservation activities and they do so all the time, so-called spill-over effects may occur (Thøgersen, 1999). While commuting by car instead of using one's bike, a person, as a trade-off, may abstain from using a dryer and fabric softener for his or her laundry. However, such spill-over is theoretically implausible, if conservation behavior falls into distinct behavioral categories (e.g., Stern, 2000b). For instance, why would someone compensate or excuse a onetime flight to a holiday resort by purchasing a new, energy-efficient refrigerator, if the two do not fall within one behavioral class? Spill-over is, however, more likely if conservation behavior is conceptualized as a goal-directed ambition, representing one class of activities (e.g., Kaiser & Wilson, 2004). Each single activity itself may or may not be particularly environmentally relevant but collectively and over time, as a behavior or a consumption pattern, behaviors nevertheless are. Limiting the scope to only specific activities or even single behaviors makes behavioral scientists ignore people's individual choice of the technical means by which they realize their personal conservation goals.

## Technology as Amplifier

In many cases, technology is an amplifier of human performance. Computers, for instance, considerably enhance our effectiveness in communicating with others, our efficiency in handling complex tasks and in retrieving information. And cars and airplanes, for example, allow people to travel more efficiently. Generally, however, the use of contemporary technology unavoidably requires the consumption of energy and natural resources, either in the original production of the technology or in its everyday utilization. As a side effect, in combination with technology, human behavior becomes progressively more consumptive as well. In other words, when behavior is augmented with technology, the consumption of natural resources is amplified too. Better engineering and redesigning undeniably have improved the resource-efficiency of many of our cherished technical appliances such as lighting systems or cars. Regarding the latter, however, despite their remarkably improved technology, the total negative environmental impact of car-use has not diminished over the last 100 years; in fact quite the opposite is true (cf. Oskamp, 2000). While most of this rise is, of course, due to the absolute increase in vehicle numbers (e.g., Heinze & Kill, 1997), some of it results from what is referred to as rebound effects.

Rebound effects can be described as the off-set part of a successful implementation of a more efficient technology, which compensates for some of its environmental gains or even negates them entirely by stimulating additional, unanticipated resource consumption, and/or use of the technology (cf. Jevons, 1865). Instead of claiming, figuratively speaking, the profits in regained leisure time, augmented car technology typically boosts individual mileage and fuel consumption. Interestingly, the proportion of time spent in cars seems to be kept constant and potential time-savings due to the more effective technology are not perceived as freed assets that could be spent otherwise. Similar to such time-related rebound effects, there are also money-related ones. This is, for instance, the case when reduced energy prices additionally spur energy consumption. Since this money could, in principle, be invested in other sorts of things, it is surprising to see that it is often reinvested in the same products or type of activity, for example car fuel, bigger cars, and increased mobility. Again, apparent economic gains do not really free any financial means. It seems as if an individual's proportion of income spent on energy represents a constant. In his review of the literature, Hertwich (2005) describes and confirms the existence of these so-called *direct* rebound effects.[1]

In environmental economics, rebound is theoretically expected to derive from either an expansion or a substitution effect (Hertwich, 2005). In this context, expansion means that technological advancements stimulate demand (e.g., in fuel use and in travel distance). For example, augmented transport technology capable of bridging distances more effectively easily results in an expansion of the original commuting distance (e.g., due to a relocation of the residence). By contrast, substitution means more fuel consumption. Now, however, this is due to a reinvestment

[1] *Indirect* rebound effects, by contrast, are not conclusively substantiated and entail a macroeconomic perspective. In other words, psychological accounts, which we discuss in the following, only matter with direct rebound effects but not with indirect rebound, such as secondary, economy-wide, and transformational effects (cf. Greening, Green, & Difiglio, 2000).

of freed economic assets into, for example, a bigger car. Both expansion and substitution imply that, for instance, the improved motor vehicle technology not only amplifies the capability to bridge distances more efficiently, but also, as a side effect, the overall fuel consumption of a person.

Regardless of whether rebound effects originate from expansion or substitution, the psychologically more interesting—but yet unanswered—question is *why* monetary and time expenditure behave as if they were roughly constant values. It is highly unlikely that there is an internal nominal value that enforces such a standard for monetary or time expenditure. In other words, we doubt that people deliberately anticipate a certain amount of time or money that *has to be spent* in a certain way, such as for commuting or for car fuel, respectively. If, however, people are neither forced nor objectively restrained to act in a particular way, they obviously have a choice. Why is it then that people do not seem to make use of the regained assets but rather reinvest them in the same objective? Why do people not save freed travel-time or fuel-money or allocate them to other types of activities (e.g., toys or computer games)?

So far, we have not been able to find any plausible psychological account for this surprising phenomenon. We believe the answer lies in some stable motives or personal reasons. In this explanation, rebound effects are caused by the same, still unattained motives that originally caused the behavior in question. For example, the lack of green space made somebody leave the city center and move to the suburbs. By doing so, he or she at the same time also expanded his or her commuting distance. As long as the original reason for the relocation (i.e., enough green space) remains insufficiently attained, commute-related freed assets, such as time and money, will be reinvested in the same activity, namely relocation to ever greener grasses in combination with ever longer commuting distances.

The amplification perspective also throws a new light on the adoption of new sustainable technologies. It suggests that the consumption of natural resources is mostly a side effect of human performance aimed to achieve other favored outcomes (see also Jager & Mosler, this issue). As a result, producers and engineers who succeed in improving the resource efficiency of a given product are essentially optimizing an attribute of secondary significance for the user. These environmental benefits may easily be dominated by the primary purpose or attribute of the product, the exception being the case that resource conservation is among the dominant goals of action (cf. Lindenberg & Steg, this issue). To illustrate, the Toyota Prius, a hybrid car, designed and marketed for its low fuel consumption and low emission rate, had a slow start in sales, because it mainly attracted environmentally concerned consumers. It failed to satisfy primary consumer needs such as for power and appearance. In other words, the amplification functions that most transport consumers focus on were comparatively less advanced. The next car model improved on these drawbacks, which led to increased sales even among customers lower in environmental concern (Janssen, 2006).

## Technology as Determinant

Technological enhancements—particularly in terms of power, efficiency, and safety—not only of cars and of airplanes but also of roads in combination with a continuous increase in air travel destinations have quite dramatically expanded individual mobility (cf. Heinze & Kill, 1997). In this section we argue that transportation technology, as an outstanding example, not only affects the environmental impact of individual transport users, but also determines people's behaviors in two distinct ways (cf. Scheuthle et al., 2005). This occurs through relevant "realization conditions," that is, the objective or tangible context in which and with which people act. First, technology instantaneously shapes—affords or restrains—behavior without requiring any recognition or awareness of the opportunities or obstructions on the actor's side (cf. McKenzie-Mohr, 2000). Otherwise, nobody would ever be surprised by a keyboard with a "mind of its own" or by some unstable steps, slippery floors, or sliding glass doors. Second, the available technology additionally affects a person's behavioral choice motivationally, that is, his or her readiness to adopt a certain technology and to act in a certain way. This occurs through confronting a person with a *tempting* opportunity or a *daunting* obstacle. While psychologists customarily acknowledge the latter, that is, the indirect or psychologically mediated effects of technology, they largely disregard the former, that is, the instantaneous technology-specific limitations and affordances (cf. Tanner, 1999).

Realizing a particular behavior inevitably requires personal resources on the actor's side, such as time, money, effort, or courage. These personal resources or, figuratively speaking, behavioral costs are not exclusively subjective as they originate from the particular realization conditions in which a behavior takes place (Scheuthle et al., 2005). For example, Kaiser and Keller (2001) found that a superior public transportation system made it effectively easier for urban than for rural Swiss to abstain from owning and using a car. This effect held true despite the fact that urban and rural residents were environmentally engaged and motivated in a comparable way. We do not claim that deterministic behavior effects necessarily are absolute. In fact we expect that instances such as when ventilation windows are technically impossible to open or when mass transit is effectively unavailable, only represent the tip of the iceberg. Rather we argue that an augmented technology gradually but nevertheless deterministically facilitates or impedes people's behaviors (Tanner et al., 2004). In other words, we believe technology to determine the relative likelihood of engagement, regardless of people's motivation to act. For example, a high density of trash receptacles, makes littering less likely for everyone, irrespective of people's tidiness because it is so easy to do the "right thing" and throw litter in a nearby trash bin.

Correspondingly, high-quality roads and good infrastructure, safe, efficient, and powerful cars, affordable gas, and a widespread proficiency to operate such vehicles are customary realization conditions in most Western-European and North-American societies. Jointly, they represent the tangible context for people's mobility; that is, an environment in which motor vehicles have undeniably become most prevalent and, apparently, the most popular means of individual transportation. Predictably, a lack of high-quality roads would already substantially change the whole situation, irrespective of people's acknowledgment of the altered situation or their personal inclination to use cars. In a similar manner the microwave oven, metaphorically speaking, paved the way for individualized eating patterns and the Internet for social networks that span vast physical distances.

Realization conditions are, however, not only the background of people's actions, which deterministically shapes what we do. They also are motivationally significant. For example, the decision a person makes to use his or her bike instead of the car to commute is partly influenced by the way a person values and appreciates, for instance, comfort and weather protection. Many reasons, most of them not conservation-relevant, eventually trigger a person's choice regarding his or her means of transportation. Someone who drives to the grocery store, for example, probably accepts air pollution at most as a side effect of driving. Intentionally though, he or she aspires to get groceries while at the same time he or she aims at increasing his or her comfort level and at decreasing transit time. In other words, the conservation-relevant aspects of driving quite often go unnoticed or are rarely taken into account. Motivationally they are therefore quite insignificant. By contrast, physical realization conditions for environment-friendly behavior, for example the availability of bike lanes or the absence of car parking space, are motivationally relevant and may stimulate the person to opt for a resource-saving alternative (e.g., Kaiser & Gutscher, 2003).

In sum, technology can simultaneously shape behavior and motivationally stimulate action, by providing an immediate deterministic obstruction or facilitation and by making the use of a certain device more or less appealing. Although this may not be a panacea, we thus expect that: (1) redesigning people's technical appliances and systems and (2) promoting superior technology are two promising ways to significantly help individual consumers to contribute to an environmentally sustainable society. In the following section we move to technology's fourth and final role, where it serves as a promoter of individual conservation behavior.

## Technology as Promoter

How can people be motivated to use scarce natural resources in a sustainable way? In the search for effective interventions we ask how modern technology can help to overcome some traditional limitations and make motivational strategies more powerful. We discuss this role of technology regarding two foremost challenges that policymakers and psychologists face in combating the major environmental risks of $CO_2$-emissions and climate change. First the use of media technologies is explored, to see how they can help enhance problem awareness. Second, we focus on interventions to change behavior and the ways technology can be used to make interventions more effective.

*Using Media Technology to Promote Environmental Concern*

Since the 1970s, governments of many countries have launched numerous mass-media campaigns to raise concern for the threats to natural ecosystems, the risks involved for human life and wellbeing, and the urgency of significant action. Results have often been disappointing. Among the many issues that have been identified, attention and processing issues form an important part (see Bartels & Nelissen, 2001, for an overview). If one looks at attention rates, many mass-media appear not to be for masses but for elites. This was recognized in the 1970s as the so-called knowledge gap. Information provided through mass-media, especially printed media, tended not to reduce, but to enlarge knowledge differences between well- and less-educated people (Tichenor, Donohue, & Olien, 1970). Relatively few people read newspapers, and printed information is relatively difficult to process. Easier accessible visual media like television ads and video clips have also been used to stimulate environmental awareness and conservation behavior. However, visual media are not more motivating per se, in spite of their easy access and less-demanding processing. This was concluded from an evaluation of mass-media public information programs in The Netherlands including the use of low-emission cars and disposal of chemical waste (Weenig & Midden, 1997). Television ads helped to create high exposure and to focus attention on the issues; over 60% of the population appeared to have watched the clips. However, knowledge of the issues did not rise significantly, neither did the motivation to read more detailed information.

New technological media though, may help to call attention to issues such as climate change, which are temporally and spatially distant, by communicating at the level of direct sensory experience instead of the usual indirect information messages. Technology mediates many of our experiences of the world, for example, when we see a piece of nature through binoculars or by watching a film. These mediations transform our perceptions, thereby emphasizing certain elements and ignoring others (see Verbeek & Slob, 2006). Multimedia technologies can add persuasive significance to the traditional communication of transferring symbolic information (like text or speech) by inducing direct sensory experiences like sounds, images, scent, and touch that create "presence," the feeling of "being there" in a mediated environment (IJsselsteijn, 2004). It may allow people to better conceptualize cause–effect relationships, such as how an urban area would look and feel like without car traffic or how the world would be after serious climate change. Empirical research to date has found effects of media from factors such as user-initiated control of the simulation, head tracking, latency, stereoscopic presentation, field of view, image motion, spatialized audio, and haptic feedback (Prothero & Hoffman, 1995; Hendrix & Barfield, 1996; Welch, Blackman, Liu, Mellers, & Stark, 1996; IJsselsteijn, de Ridder, Freeman, Avons, & Bouwhuis, 2001; see IJsselsteijn, 2004, for an overview).

More recently, significant research efforts have been directed towards investigating the relation between "presence" and emotional impact (measured through, e.g., galvanic skin response or heart rate variability), where findings are supportive of the existence of such a relation (De Kort, Meijnders, Sponselee, & IJsselsteijn, in press; Dillon, 2006; Lombard, Reich, Grabe, Bracken, & Ditton, 2000), in particular in relation to fear-inducing media environments (Meehan, Razzaque, Whitton, & Brooks, 2003). Research in the domain of environmental risks has convincingly demonstrated the role of affect and emotion in risk perception (e.g., Slovic, Finucane, Peters, & McGregor, 2004). However, research work in this domain that examines the effects of emotions in persuasive messages, is still in its infancy. Some experimental evidence is available, which shows that video images with emotionally charged content stimulate attention for climate risks and coping options. The use of intrusive images and dramatic sounds to alert people were found to enhance relevant information processing for coping with these risks (Meijnders, Midden & Wilke, 2001a, 2001b). A survey among American viewers of the movie "The Day after Tomorrow" (2004; dramatizing how, due to global warming, a new ice-age emerges and New York is flooded by a giant tidal wave), showed that the film led moviegoers to have higher levels of concern and worry about global warming and to estimate various impacts on the United States as more likely (Leiserowitz, 2004).

These studies suggest a new area of inquiry in which virtual environments will be used to offer new opportunities for technology assessment by giving people pre-experiences of future technology effects or newly planned environments and facilities, which will go beyond verbal descriptions or abstract representations. These types of systems persuade at the intuitive level by giving persons a better "feel" for the future or other distant environments and to experience not directly observable cause–effect relationships. The Day after Tomorrow demonstrated that it might help to make risk communication part of popular culture and to use its new media, like immersive video and gaming (Leiserowitz, 2004).

In sum, traditional media have had limited success in promoting environmental problem awareness, but new multimedia technologies show more promise in this endeavor by offering new opportunities for creating and enriching sensory experiences as a route to raising awareness of future and/or distant issues, to explore cause–effect relationships, and to experience environments that are not directly observable. However, despite the possibilities offered by multimedia technology, raising awareness will not be enough to fight climate risks and diminish the use of natural resources. In the next section we turn to the role of technology in accomplishing behavioral change.

*Using Smart Technology to Promote Energy Conservation Behavior*

Using electronic devices has shown how they might contribute to the efficiency and effectiveness of behavioral interventions, but technology just was not yet smart enough in most cases to make these devices very successful. Because psychology has only recently had access to more advanced technology, psychologists have as yet merely touched upon the opportunities offered by smart systems to promote (energy) conservation behavior. Although energy conservation behavior is clearly relevant in many contexts, here our focus is on the home situation as an important environment in which many interactions between technical systems and human behavior can be observed. Most early work was done on the effects of feedback on energy consumption. Studies often used simple procedures like written messages based on daily or weekly meter readings, while some researchers used electronic displays (see, e.g., Abrahamse, Steg, Vlek, & Rothengatter, 2005).

The purpose of developing electronic modes of feedback has been to solve a number of issues related to written modes. First, the results of the written forms of feedback appeared sensitive to the frequency of the feedback. Delays between action and feedback reduced the effects (e.g., Pallack, Cook, & Sullivan, 1980). Electronic means could provide feedback more quickly and frequently than written feedback, even continuously, thus making the consequences of specific behaviors better available for the consumer. Second, while many consumers had difficulty in reading meters or bills, electronic feedback could be given at more central locations like the living room or the kitchen. Third, the written forms were limited and uniform in the information that could be provided (e.g., Midden, Meter, Weenig, & Zieverink, 1983). In contrast, electronic feedback allows for the use of multiple standards (e.g., personal and social), reference points (e.g., financial costs per hour, the previous day or the upcoming month), and units (e.g., $ or kWh) (e.g., Hutton, Mauser, Filiatrault, & Ahtola, 1986). Some studies tested PC- or web-based systems (Brandon & Lewis, 1999; Ueno, Inada, Saeki, & Tsuji, 2006) or systems that used a television channel (Völlink, 2004). These systems allow for presenting detailed and complex information, often with the help of attractive graphics. On the negative side, these systems suffered from lower accessibility than the wall-mounted devices. Fourth, written feedback provided with a high frequency has been quite effortful and costly. Automation could make the feedback process more efficient. Fifth, in most cases feedback was aggregated at the household level, making it difficult to attribute the effects to specific uses, appliances, or persons. Electronic feedback could be source-specific (e.g., the airco or the cooker), evidently creating a closer link between feedback and action (Wood & Newborough, 2003; Ueno et al., 2006).

*What Can We Learn from These Experiences?*

It is not easy to draw firm conclusions on the effectiveness of the various technologies, because applications of technical devices have been diverse, experiments have had different setups, and target behaviors referred to general or specific sources of energy use. Monitors often displayed different data such as financial costs versus consumed energy and various frames. In spite of these factors, some cautious conclusions can be drawn. Electronic means have made it easy to provide highly frequent feedback, which is more effective. Electronic devices have also facilitated feedback on specific appliances, which appeared to be more effective than general feedback (a.o., Ueno et al., 2006). Goal-setting, added to electronic feedback, enhanced energy savings (Van Houwelingen & Van Raaij, 1989; Völlink, 2004).

Surprisingly, the ergonomics of the devices have hardly ever been addressed (but see Wood & Newborough, 2003). For example, situational factors such as noise or sunlight can limit the readability of the devices. Ambiguous dialogues or unclear symbols may hamper message understanding, and sources with low access will require more motivation. Unfortunately, these factors have rarely been manipulated, measured, or reported.

Overall, studies have primarily tested a finished prototype, making it difficult to draw specific conclusions by disentangling particular characteristics or attributes of the system and the intervention. This highlights a more general issue of design. Psychologists often enter the process too late, after the design has been completed and the test phase has started, which makes it impossible to bring in feedback specifications and ergonomic requirements (see, e.g., Seligman & Hutton, 1981).

Almost all interventions were designed to communicate with subjects in a one-way direction. Modern intelligent systems enable two-way interaction between user and system, which allows for more precise targeting of tasks and for personalization. To illustrate, interactive systems allow for the implementation of more refined goal-setting procedures and the provision of more specific information, not only to specific appliances but to specific tasks as well. Interactive devices are still rare in the domain of (energy) conservation behavior. Some studies, however, illustrate the potential (McCalley & Midden, 2002; McCalley, 2006). They achieved energy conservation results up to 20% using washing machines with a user interface that allowed for interactive goal-setting and outcome feedback. During a series of 20 washing tasks, users received immediate feedback each time they made a choice for a washing program to carry out a particular task. Subjects with either self-set or assigned goals saved more energy than subjects without an explicit goal. In a follow-up field experiment the effectiveness of interactive feedback procedures was confirmed, bringing about 18% of saved energy compared to the use of the same machine, but without the feedback system.

*Future Developments*

Future developments in information technology will enhance the role of supportive systems by applying intelligent agent technology that learns from the users and interactively communicates on a personal basis. Such agents take into account the tasks to be done and the goals to be achieved. They are able to frame outcomes based on the current context or user, or encourage the user to make certain goals more explicit, and even make suggestions on how to act or guide a user to a decision. Because they act at the right place and time, these systems can be very powerful. In this role, intelligent agents may become persuasive social actors (Fogg, 2003) rather than simple tools. The "similarity studies" of Stanford University provided evidence that the similarity principle of persuasive communication also applies to computers in the role of change agent. Experimental participants preferred working with a computer they perceived to be similar to themselves in personality style; dominant persons preferred a computer that communicated in a dominant style, while submissive people preferred a submissive computer.

In another study, people who worked with a computer that was labeled as their teammate reported that the computer was more similar to them, smarter, and that it offered better information and problem solutions. Hence, similarity in "personality" and "group affiliation" between computers and users made a favorable difference when it came to persuasion (Fogg, 2003; Nass & Moon, 2000). Future research should reveal to what extent these systems will be able to fulfill capabilities of human change agents like giving social incentives, creating commitment, and building credibility. Intelligent systems with these features and objectives have recently been referred to as "persuasive technology" (Fogg, 2003).

Technological assistance may go beyond the level of specific appliances and direct energy use. Modern home domotics (the application of computer and robot technologies to domestic appliances) will be able to monitor multiple sources of energy use and support home energy management. Such systems will offer advice on saving options taking account of personal lifestyles and even support strategic decisions like investments in equipment and home renovation.

Persuasive technology is not limited to verbal communication, but may (also) utilize other forms of sensory information like changing colors or sounds. Such systems can inform users at an intuitive level, demanding little cognitive effort. Interesting demonstrations and concepts have recently been developed in the design community. For example, the Power-Aware cord (Gyllenward & Gustafsson, 2005) is a strip on a power cord designed to visualize along the cord the electric current passing through, by glowing pulses and intensity of light. The idea is that by getting this visual feedback of the presence of energy, people will be stimulated to think about their electricity consumption at home. Another idea is "disappearing-pattern tiles" (Lagerkvist, Von der Lancken, Lindgren, & Sävström, 2005). Bathroom tiles are decorated with patterns in a thermo-chromic ink that reacts to heat by fading away. The design is meant as a subtle reminder of personal energy use during a shower. These examples show another trend, in which intelligent systems will no longer be located in home computers or special boxes, but will be integrated within the living environment. The concept of ambient intelligence refers to the emergence of intelligent environments that sense what a person would need. One example might be that sitting quietly for some time means that the temperature should go up, but regular movement may signal to the system that the temperature can be reduced, making the user more comfortable and saving energy at the same time.

This type of technology can make information accessible where needed by the user or, taking one step further, no longer include the user in the decision process, raising new issues particularly related to the question how to allocate control between smart systems and users.

## Allocating Control: A Central Issue

Our review of the four roles of technology—as intermediary, amplifier, determinant, and promoter—suggests that both consumption and the sustainable use of natural resources are the result of the different ways in which humans interact with technology. Essentially, however, the availability of technical systems is based on human decisions. A requirement for making technology work is that people actually use the systems and let them conduct these roles. An intelligent in-car navigation system can only produce the shortest route to a destination if the user is willing to use the system and rely on its guidance. In other words, technological efficacy demands that the user is willing to delegate control to a system for carrying out a task. The trend is unmistakable: increasingly, human tasks are being taken over by self-regulatory systems, such as route navigation or indoor climate control. People seem motivated to reduce personal efforts by implementing automated systems and make life easier, reduce errors, and improve safety. However, automation is not always beneficial for the user. Every user of an automatic system will experience system errors and the system's inability to deal with complex tasks. As a result the user may react by refraining from use at all. Clearly, a proper tuning of task and control allocation is essential.

An example of a proper balance in control allocation was reported in a study on lighting in an office environment (Van Kesteren, 2006). The study tested a lighting control setup in which employees could establish a lighting level between 20 lux and 800 lux using a control device. The system automatically controlled the lighting level depending on daylight availability and included an absence detector that automatically switched off the light after 15 minutes of absence. The experiment resulted in a huge energy conservation effect on lighting of 37% and users appeared happy with the automatic controls by the system. The evaluation suggested that the availability of the control device strengthened people's feeling of control.

Trustworthiness of the system will help a lot to achieve user cooperation. However, trust in systems is not always correctly calibrated (Lee & Moray, 1992).

People may overestimate their own abilities as compared to the system, which may lead to suboptimal choices, fatigue, and human errors. Alternately, trust may also be unjustified, leading to lowered vigilance for system errors and decreased situational awareness, which may reduce opportunities to intervene effectively. De Vries, Midden, and Bouwhuis (2003) showed how subjects developed trust or distrust in a system, using a route planner. It is not only the final result that counts. People make use of various cues in the interaction process, such as linked to the dialogues and displays during the interaction, for example the displayed route map. Hence, acquiring trustworthiness poses a challenging requirement for product designers.

Ethical issues of privacy and free choice may arise when users do not really have a choice of use but are ignorant, such as in the case that intelligent systems sense user behavior and act accordingly. For example, customers' purchasing patterns may be observed in a store and subsequently used to send out advice to customers by cell phone to buy sustainable products. Designing and constructing systems and interfaces that users want to rely on will probably be one of the greater challenges requiring collaboration between technologists and behavioral scientists.

## Conclusions

In this article we aimed to bridge the gap between technological and psychological approaches to resource conservation by analyzing the consumption of natural resources as the result of long-standing and continuous interactions between humans and technical systems. Our analysis shows how behavior and technology are closely interwoven throughout life in bringing about more or less sustainable consumption patterns. The modest attention that the role of technology receives in psychology and in policy making is therefore surprising. We believe that interactive approaches that integrate the behavioral and technological factors have an added value compared to singular, mono-disciplinary approaches, particularly by supporting the design and redesign of technical products, systems,and environments that optimize conservation behaviors and environmental effects. To improve our understanding of these interactions four roles of technology were identified: technology as an intermediary between behavior and conservation outcomes, as an amplifier of human performance and—as side effect—of environmental resource consumption, technology as a determinant of behavior—shaping and channeling behavior, and as a promoter of conservation motivation and/or behavior.

We do not claim to have already reached an integrated understanding of human–technology interactions. However, each of the four roles is meant to reveal in a different way how human–technology interactions affect resource consumption and which routes to conservation can be identified. Technology's intermediary role reflects how the environmental impacts of individuals' actions depend on the technology used. However, the choices and tradeoffs to be made by consumers appear to be highly complex and full of uncertainty. Consumers need help in making these choices, for example through product labeling. Preferably, consumers should be supported on the level of their behavioral patterns, taking into account their personal, overall ecological footprints. Intelligent devices, at home or mobile, could provide assistance to the consumer, by helping individuals and households in making better choices and developing their own sustainable lifestyles. Importantly, developing these tools requires contributions from both engineering and psychology.

The amplifier role of technology demonstrates that, in the eyes of the consumer, effects on natural resources are often side effects of technology use. Rebound effects occur because efficiency gains, for example of light bulbs, may not reduce the original primary purpose of the technology, such as luxuriously illuminating the home, and might even increase the consumer's desire for more extensive illumination. This analysis makes us aware that conservation policies, in spite of technological progress, cannot do without people's general motivation to contribute to the sustainable use of natural resources, which should thus stay high on the agenda of both psychological researchers and policy makers. Psychologists are also faced with the intriguing issue of finding a psychological account of the rebound phenomenon and in answering the question why consumers tend to reinvest regained assets in the same class of activities instead of allocating them to other activities as well.

Another implication of the amplification analysis concerns the design and marketing of sustainable products. Perhaps counter-intuitively, it suggests that emphasizing the environmental benefits of a new product might be negative for its adoption, in particular when the consumer is primarily searching for other performance attributes. Clearly, the challenge lies in designing products and systems that are appealing to consumers beyond a "green" niche market by delivering the performance needed, while also minimizing the consumption of natural resources.

Technology not only influences the outcomes of behavior. As a dominant context that is creating the conditions for most human behaviors, it also directly influences behavior by affording or restraining it. This is the determinant role of technology. Typically, such effects are instantaneous and do not require awareness or reasoned intentions on the user's side. A better understanding of these influences could open a route to resource conservation through the design and redesign of technological environments, like homes, offices, roads, and communication media that afford users the opportunity to act in a "sustainable" manner.

To illustrate, highly advanced car technologies promise to take care of electronically managing the distances between cars on highways. Using such systems might help car users to drive at a more constant speed, thereby reducing fuel consumption and increasing road safety. This example also highlights a more general issue of technological solutions: the willingness of consumers to use technology. Modern systems gain intelligence at a dazzling pace, but they risk a loss of transparency and predictability at the same time. This signifies the issue of user acceptance and people's willingness to trust and delegate control to such systems.

Finally, the promoter role deals with the use of technology to motivate people. Our review reveals that technology has a lot to contribute to the design of effective motivational interventions. It helps to raise awareness of future or distant issues, such as the vast melting of polar ice, or to lower thresholds for change, for example by making it possible to experience a building not yet constructed or to explore cause-and-effect relationships such as the effects of ventilation on air circulation in the home. Technology can be a powerful tool to motivate people to change behavior in almost any domain of daily life, whether at home, "en route," or at work. To be successful, policy makers and scientists alike should relate to these rapid developments and attune their interventions to "smartened" living environments and novel communication media. Smart technologies enable personalized interventions at the time and place that consumption decisions are made. An example is the cell phone that helps its user on the spot with purchases to select the product that fits his/her needs and has the best energy-efficiency.

Interventions that aspire the integration of psychological and technological means form a challenging perspective. Bringing together psychological and technological expertise may not be an easy task. We believe, however, this effort to be most worthwhile on the route to a society that makes sustainable use of its natural resources.

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